Report for 2004NJ74B: HIgh resolution geophysical imaging as a novel method for noninvasive characterization of contaminated wetlands: application to Kearny Marsh

- Conference Proceedings:
    - Mansoor, N. and Slater, L., 2004, Integrating high-resolution geophysical technologies with a GIS-based decision support system into evaluation and management of wetlands, 2004 Joint Assembly, American Geophysical Union (AGU), Canadian Geophysical Union (CGU), Society of Exploration Geophysicists and Environmental and Engineering Geophysical Society, May 17-21, Montreal, Canada, Abstract NS13A-02
- Other Publications:
    - Mansoor, N., 2005, High-resolution geophysical characterization of shallow-water wetlands, Meadowlands Environmental Research Institute Spring 2005 Seminar Series, May 4 2005, http://meri.njmeadowlands.gov/2005seminar.html
- Articles in Refereed Scientific Journals:
    - Mansoor, N., Slater, L. and Artigas, F., 2005, Case history: High-resolution geophysical characterization of shallow-water wetlands, Geophysics, Submitted 01/20/05

Report Follows

PROJECT INFORMATION

Problem

Geophysical technologies permit non-invasive assessment of physical properties of the subsurface. These physical properties are a function of the pore fluid composition and hence sensitive to contaminant concentration. Wetland sediments and pore waters are often cumbersome to sample directly. Geophysical technologies are increasingly used on land for rapid, non-invasive, environmental contamination assessment. I propose to develop data acquisition, processing, interpretation, and integration protocols to permit effective transfer of state-of-the-art geophysical technologies to the study of shallow water wetlands. I argue that geophysical technologies, hitherto rarely utilized by wetlands scientists (primarily ecologists, geochemists and hydrologists), can significantly improve understanding of shallow-water wetland environments.

Research Objectives

The project has four primary research objectives designated A-D below.

A. Advancement of the implementation of geophysical technologies in wetland environments from shallow-water boats: We propose the use of a four person paddle boat as used for recreation on small lakes/ponds as a "research vessel" for geophysical studies in wetlands. Advantages of these boats include: (a) very shallow draft permitting operation in less than 1 ft standing water (b) adequate space for two persons plus high accuracy GPS unit, geophysical instrumentation, surface water quality probes, and laptop (c) all plastic construction minimizing interference of the boat with geophysical measurements (d) hands-free control permitting operation of geophysical instruments whilst surveying.

B. Development of a protocol for the integration of geophysical datasets within a 3D and 4D spatial GIS framework: High data density obtainable with state-of-the-art geophysical instrumentation will result in spatially extensive 3D and 4D datasets. Geographical information system (GIS) databases are appropriate for managing and visualizing multiple types of data, including high-resolution geophysical data as to be obtained in this study. We will determine how spatially and temporally extensive geophysical data can be organized within a wetland GIS to integrate information into a coherent georeferenced framework suitable for analyses and decision making.

C. Implementation of high resolution geophysical imaging for monitoring solute release from landfills fringing on wetlands: We will investigate how electrical imaging can non-invasively delineate and temporally monitor contaminant plumes entering wetlands.

D. Concept application and testing in Kearny Marsh, Hackensack Meadowlands, New Jersey (Fig. 1): We will adopt this integrated geophysical/GIS approach to (a) evaluate the primary sources contributing to pollution of Kearny Marsh; (b) determine the distribution of these pollutants within the marsh; (c) assess seasonal/hydrological controls on pollutant fluxes. Geophysical data interpretation will be constrained by direct sampling of sediments and pore waters, surface water chemistry and hydrogeological measurements of the groundwater surface around primary contaminant source zones.

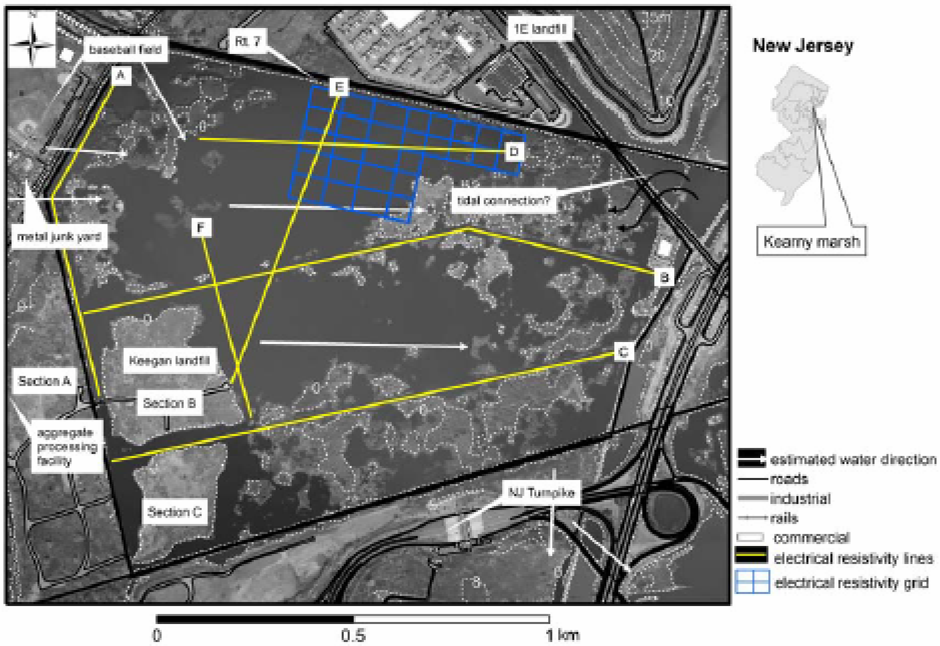

Figure 1: Site map delineating Kearny Freshwater Marsh and showing identified potential contamination source zones. The yellow lines define the 2D electrical imaging lines and the blue grid outlines the proposed 3D resistivity monitoring experiment.

Methodology

The work to date has involved five primary tasks: (1) reconnaissance geophysical and surface water surveys of Kearny Marsh to rapidly assess likely contaminant source zones; (2) water and sediment sampling and geochemical analyses; (3) laboratory electrical measurements to determine the sensitivity of electrical parameters to heavy metal contaminants in the marsh sediments; (4) time-lapse electrical resistivity imaging along a number of monitoring transects adjacent to suspected contaminant source zones; (5) integration of geophysical datasets within a GIS framework for data management and visualization.

Reconnaissance geophysical and surface water surveys:

We utilized an all-plastic (excluding the steering mechanism) four-person paddleboat, typically used for recreation on small lakes/ponds, for rapid acquisition of geophysical data in shallow water wetlands (Fig. 2). The shallow draft (approximately 0.3 m) of this boat is ideal for operation in such wetlands. The paddleboat was equipped with the following instrumentation: a high precision Trimble® differential GPS unit (location accuracy = ± 25cm), digital surface water quality probe (temperature, pH, electrical conductivity, salinity, total dissolved solids, dissolved oxygen, turbidity and water depth), digital magnetic gradiometer or digital terrain conductivity meter and a waterproof laptop.

All instrumentation was programmed to automatically record a measurement every two seconds during surveys. Geophysical data acquisition rates exceeded 10 km of line (+ 12,000 measurements) per eight-hour field day.

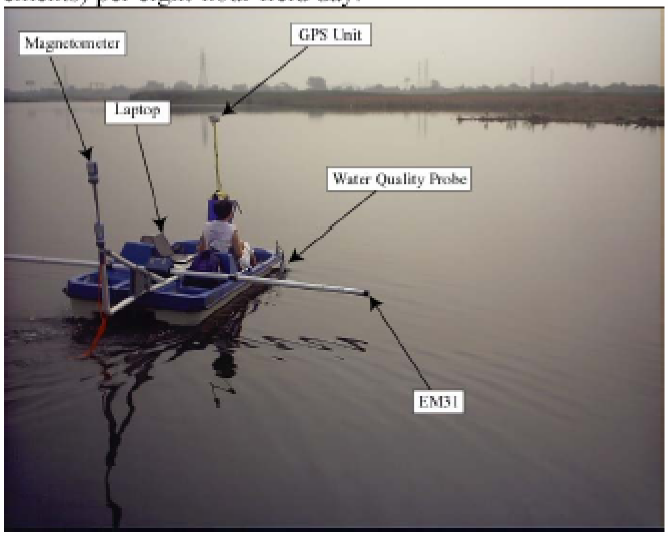

Figure 2: Paddleboat in operation on Kearny marsh showing on-board instrumentation. Note: both the magnetic gradiometer and the terrain conductivity meter are shown for illustration purposes only; Data are collected on separate surveys to avoid interference between instruments.

The EM31 terrain conductivity meter was mounted to the paddleboat with a fixed orientation perpendicular to the survey direction (Fig. 2). Due to the shallow water depth, the EM31 response primarily reflects the electrical conductivity of the sediments, as we shall show. A Scintrex Envi™ gradiometer was employed with the sensors mounted 1.5 m behind the boat from a PVC frame in order to avoid interference from the metallic parts of the steering mechanism and other equipment in the boat. Surface water parameters were measured simultaneous to geophysical measurements using a Hydrolab™ probe mounted to the front of the paddleboat. The measured parameters were surface water electrical conductivity, pH and water depth. The electrical conductivity of the surface water helps constrain any dependence of the EM31 terrain conductivity measurement on the surface water layer. All terrain conductivity, gradiometry and surface water chemistry data were recorded every two seconds whilst in survey. Data from each survey period were spatially referenced using the synchronized time stamps provided by each instrument and the GPS unit.

<u>Sampling and geochemical analyses</u>:
We collected twenty eight surface water and bottom sediment samples to investigate the cause of terrain conductivity variation recorded in our reconnaissance surveys. The sediments samples were obtained using an AMS extendible lake sediment corer equipped with a drop hammer without rotary operation to minimize disturbance. The samples were collected directly into plastic liners placed into the coring device and then sealed with plastic end caps to prevent water evaporation. Depth of sampling ranged between 0-60 cm from the top of the marsh sediments. Sample locations were selected to investigate

trends in the terrain conductivity data. Pore waters were extracted from the samples by centrifuging and filtering the liquid with a pressure vacuum.

The bottom sediment samples were prepared and analyzed using the MERI labs during October and November (2004) in accordance with the EPA sampling and preparation standards. Major heavy metals as well as major anions and cations were analyzed for both the sediments and the surface water. Furthermore, the pore water extracted from the sediment samples were also analyzed for major cations and anions as well as iron content. Pore water extraction was performed by centrifuging each sample and then by applying a high pressure vacuum for water extraction. The sediment samples were acid-digested in an OI-7295 microwave digestion system. A Varian SpectrAA-220 fast sequential Atomic Absorption Spectrometer was used for all chemical analysis. Quality control was performed by analyzing the reagents, blanks, standards and duplicate samples for each sampling preparation event. Recovery percent for the sediments samples ranged from 96 and 103% and with a maximum error of ±3.5%. Tables 1 through 4 represent the detailed results of the chemical analysis of the different matrices.

Laboratory electrical measurements:

We measured the low-frequency (complex conductivity) electrical properties of the twenty eight sediment samples obtained. Four electrode measurements were conducted with a dynamic signal analyzer (DSA). Current was injected at the stainless steel mesh electrodes and sample voltage recorded using Ag-AgCl electrodes. A pre-amplifier was used to boost the input impedance on the voltage channel to approximately 10^9 ohms in order to avoid current leakage into the external electrical circuit. Any residual frequency and sample resistance dependent phase response resulting form the external circuitry was removed by performing calibration measurements of pure electrolyte solutions. The phase shift and conductivity magnitude for the samples were determined relative to a reference resistor for forty measurement frequencies spaced at equal logarithmic intervals from 0.1 to 1000Hz.

Time-lapse electrical imaging

We established six transects for time-lapse electrical imaging designed to investigate solute transport from suspected contaminant source zones (Fig. 1). The first dataset was collected in September, 2004 and subsequent datasets were collected at biweekly intervals. This work is still in progress. Electrical imaging is performed by towing a floating electrode array from the back of the paddleboat. A state-of-the-art ten channel Syscal Pro (Iris Instruments, France) resistivity imaging system is used for data acquisition. We utilize the 'Sysmar' marine data acquisition software developed by Iris Instruments for continuous (in survey) electrical imaging. In this mode, 10 four electrode measurements are collected every two seconds as the survey progresses. A high precision Trimble® differential GPS unit (location accuracy = ± 25cm) is used for spatial location. Water depth and surface water conductivities are also collected during resistivity surveys. The electrical datasets are inverted for a two dimensional distribution of resistivity along the survey line using the RES2DINV software that has a built in option for processing continuous marine datasets collected from floating electrode arrays. The RES2DINV allows also in integrate the bottom sediment profile (elevation) as well as the conductivity of the surface water layer minimizing artifacts in the data inversion.

GIS integration and visualization

We used a GIS database to manage, process, visualize and interpret the high-resolution geophysical data. This database incorporates previous data, maps, aerial photographs and geophysical data into an analytical environment, permitting easy modification and updating with the acquisition of additional data. The database defines several spatial themes such as landuse zones, transportation networks and industrial facilities. Existing surface water and sediment geochemical data were converted to database tables and imported into our GIS framework.

Spatial image creation for the terrain conductivity and the measured surface water parameters was performed in GIS ArcEditor® 9.0 using the Inverse Distance Weight (IDW), a deterministic interpolation tool that weights the distance and magnitude of the surrounding points and determines the smoothness of the resulting surface. The best results from IDW are obtained when sampling density is high, as in the case of our geophysical/surface water quality datasets. The IDW method attenuates the relative influence of distant data points on the local interpolation. The barrier option in GIS, defining linear features with no z value, was used to specify the location of features known to interrupt the surface continuity and appropriately limit the selected set of input sample points used for the interpolation. Barrier features were created by outlining the Phragmites Colomiza within the study area as well as the boundary of the marsh.

Principal Findings and Significance - Progress Report

Reconnaissance geophysical surveys

Our surveys reveal a detailed patterning in both the surface water chemistry and geophysical measurements of the subsurface of Kearny Marsh. The surface water conductivity image reveals highest values in the central and northern parts of the marsh and shows no evidence for a tidal connection to the marsh in the east/northeast corner of the marsh as suggested based on hydrological measurements. The surface water measurements also suggest that there is no significant surface water plume associated with the Keegan landfill.

The terrain conductivity image exhibits a distinctly different pattern from that apparent in the surface water image and illustrates that the geophysical measurement is sensitive to the sediment properties (Fig. 3a). Most significant is the region of high terrain conductivity mapped in the northeast corner of Kearny Marsh. This may reflect the presence of a groundwater plume emanating from the 1E landfill or it may alternatively indicate a lithological change with electrically conductive sediments towards the northeast. Available lithologic data do not indicate any significant lithologic change in the upper 3 m of sediment. Pore water conductivities measured from samples collected close to the metal junkyard and the baseball field are between 0.900 and 0.125 S/m, whereas sediment samples collected from the northeast corner of the marsh close to the 1E landfill exhibit the highest pore water conductivities ranging between 0.200 and 0.300 S/m (Fig. 3a). We therefore conclude that the high terrain conductivity values are likely due to the presence of subsurface contamination from landfill leachate, and not to lithological variations. The terrain conductivity data also indicate a possible groundwater plume from Section C of the Keegan landfill but restricted to the east (Fig. 3a). The pore water samples collected around the Keegan landfill have conductivities ranging from 0.125 S/m west of the landfill to about 0.175 S/m to the east.

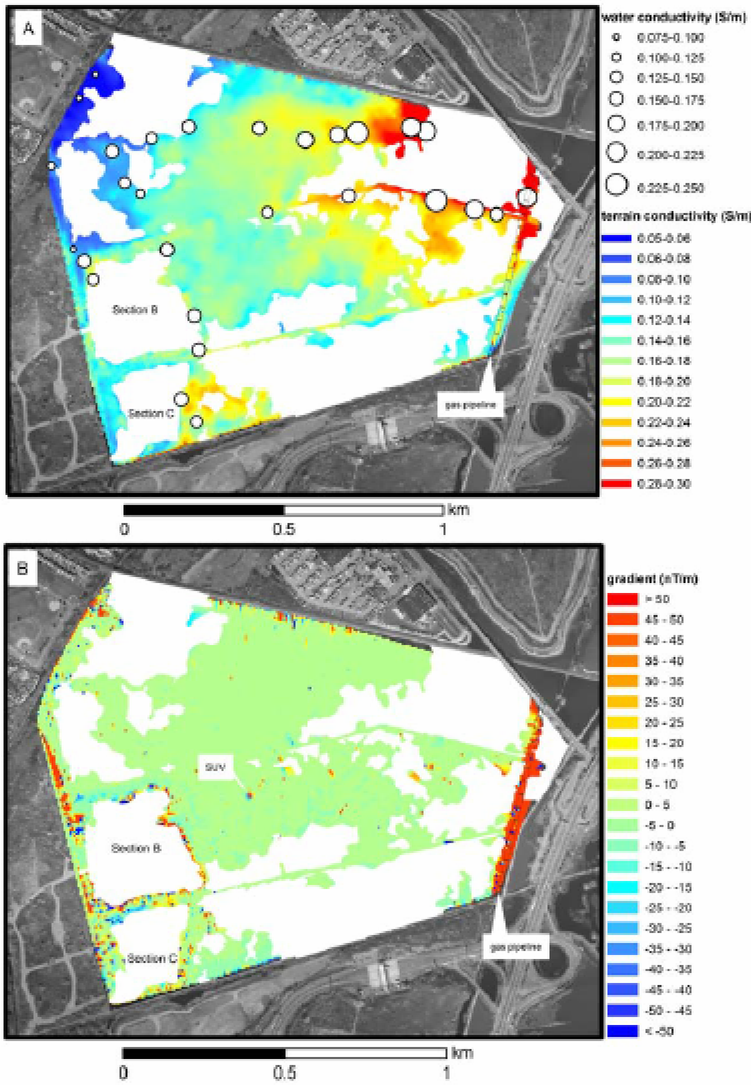

Figure 3: a) A spatial image showing: (1) the terrain conductivity (in S/m) generated from the high-density geophysical data measurements, and (2) conductivity of pore water (in S/m) from 28 sediment samples, (b) magnetic gradiometer spatial image (in nT/m) generated from the point-based measurements taken within Kearny Marsh.

Sampling and geochemical analyses

The most significant results from the geochemical analyses on the samples and pore waters pertain to the heavy metal analyses. Consistent with previous studies in Kearny Marsh, our work has revealed high levels of heavy metal contamination in the marsh sediments. Our datasets suggest that the heavy metal concentration increases towards the 1E Landfill in the northeast corner of the marsh.

Laboratory electrical measurements

The laboratory electrical measurements have been completed but modeling of these datasets remains a work in progress. The initial results suggest that there is a relationship between the magnitude of the interfacial polarization of the sediments determined from Cole-Cole relaxation modeling and the total heavy metal concentration. However, the variation in the iron concentration between samples is a factor that influences the electrical measurements and complicates interpretation. This aspect of the work will be fully detailed in our final report.

Time-lapse electrical imaging

This work remains in progress. Our preliminary findings indicate that the resistivity images obtained along the established monitoring transects are consistent with our EM31 reconnaissance datasets. However, the resistivity images provide additional information on vertical resistivity structure that may relate to the shape of solute plumes. Furthermore, we hope that the electrical resistivity imaging at various time intervals will also reveal subsurface contaminant fluxes in response to hydrologic forcing. This aspect of the work will be fully detailed in our final report.

GIS integration and visualization

The GIS database and visualization has proven highly effective for managing and interpreting our geophysical datasets. A good example of its effectiveness is the evaluation of the magnetic gradiometry datasets collected as part of the reconnaissance geophysical surveys. This survey mapped the distribution of buried metallic debris within Kearny Marsh that reflects a legacy of land misuse and environmental degradation (Fig. 3b). Aerial photographs from 1969, when the landfill was operational, support this concept. These photographs were precisely rectified and spatially registered into the GIS environment for comparison with the geophysical data. The old boundary of the Keegan landfill and old access roads were identified and outlined. The gradiometer data were then overlain on the 1969 photograph. The resulting image shows that the gradiometer data appear to map the maximum operational extent of the Keegan landfill (Fig. 4). Water levels within Kearny marsh have increased since 1969, covering the edges of the Keegan landfill and changing its morphology as well. We also find that the gradiometer anomalies mapped peripheral to the Belleville turnpike and along the southern parts of the Keegan landfill are in alignment with access roads that existed in 1969. The gradiometer data therefore seem to reflect historical dumping associated with these access roads. Illegal dumping is also associated with marshland immediately proximal to the metal junkyard and the baseball field.

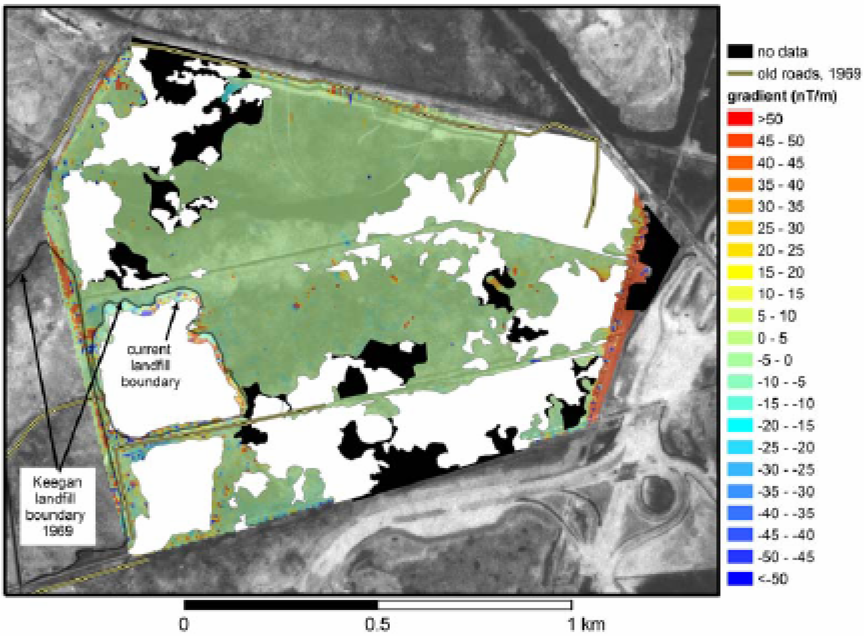

Figure 4: A multi layer spatial image showing (1) aerial view of Kearny Marsh in 1969, (2) the extent of the Keegan landfill during operational time and the trend of old roads are outlined, (3) magnetic gradiometer image with 50% transparency, and (4) current dry and vegetated areas within Kearny Marsh.